Prototype NOvA RF Cavity for the Fermilab Recycler Ring

Heba Elnaiem

Fermi National Accelerator Laboratory
&
Howard University
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NOvA

(NuMI Off-Axis Electron Neutrino Appearance)

- Objective: to search for evidence of muon to electron neutrino oscillations.
- Significance: oscillations will answer such questions as the ordering of the neutrino mass states.
- Location: slightly off the centerline of existing NuMI beam.
  - Allows for large neutrino flux that peaks at 2 GeV, the energy where oscillations to electron neutrinos is expected to be a maximum.
- The Recycler ring will be converted to a pre-injector to the Main Injector.
- Reduces cycle time from 2 sec to 1.33 sec

Slip Stacking in Recycler Ring

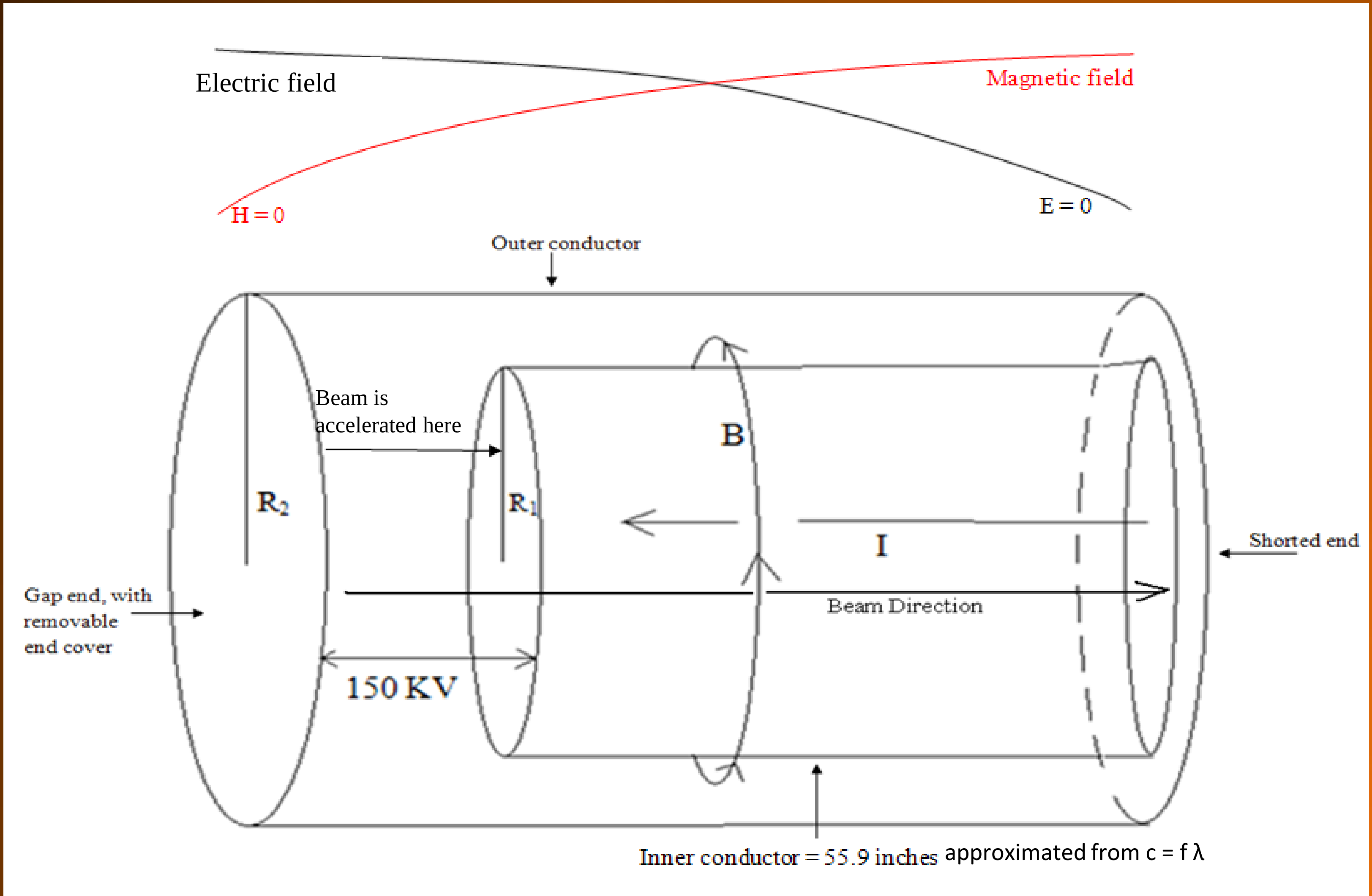
- Six Booster batches are injected and captured by the first RF cavity at 52.814MHz, then decelerated.
- The second RF cavity is off during the first 6 batch injections.
- Next six batches are individually injected at 53.814MHz and captured by the second cavity and then accelerated.
- 2 sets of batches have different frequencies and energies.
- After the 12th batch injection, both sets are aligned to 52.814MHz so they line up longitudinally [4].
- Then, beam is extracted and injected into the Main Injector (MI).
- Now MI will accelerate 6 booster batches with twice as many protons.

Project Objective

1. To build a low power, inexpensive prototype for the $2 million NOvA RF cavities that slip stack.

2. To measure as many factors about the prototype as possible.

Coaxial λ/4 Resonator RF Cavity



Cavity Dimensions

- Center Frequency = 52.814MHz
- Gap voltage = 150kV.
- Power Available = 150kW.

$$R_{sh} = \frac{(V_{gap})^2}{2P}$$

- R_{sh} = 75,000Ω
- R_{sh}/Q = 14Ω; vs. current cavities with R_{sh}/Q = 106Ω
- A low Rsh/Q is desired in order to reduce beam loading effects.
- Q = 5000.
- $r_2 \leq$ 17 inches because of location where it can be installed.
- r_1 and r_2 can also be calculated from:

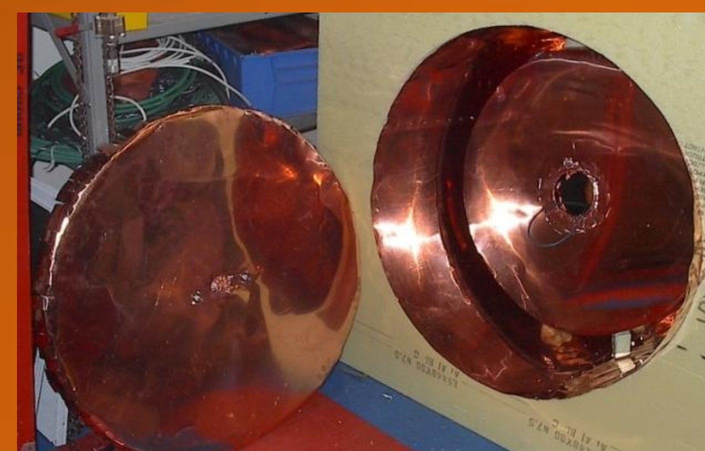
  where σ is the conductivity of copper.

$$Q = \frac{\omega L}{R} = \frac{2\,(\pi\mu_o\sigma f)^{1/2}\, r_1 \ln\frac{r_2}{r_1}}{1 + (r_2 / r_1)}$$

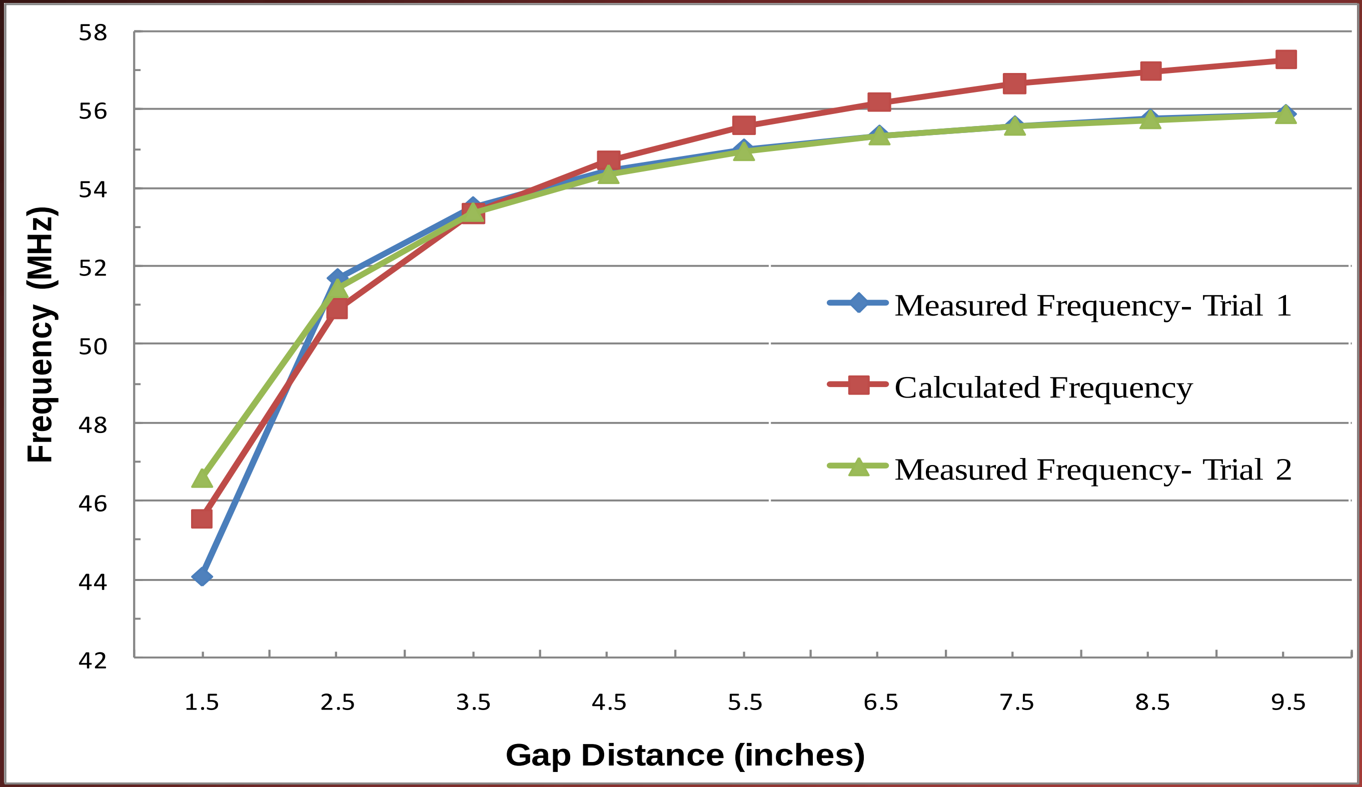
- r_1 = 13.38 inches
- r_2 = 16.07 inches

Cavity Construction

End plate with the Forks, which act like springs and make good electrical contact.



Gap Distance vs. Frequency

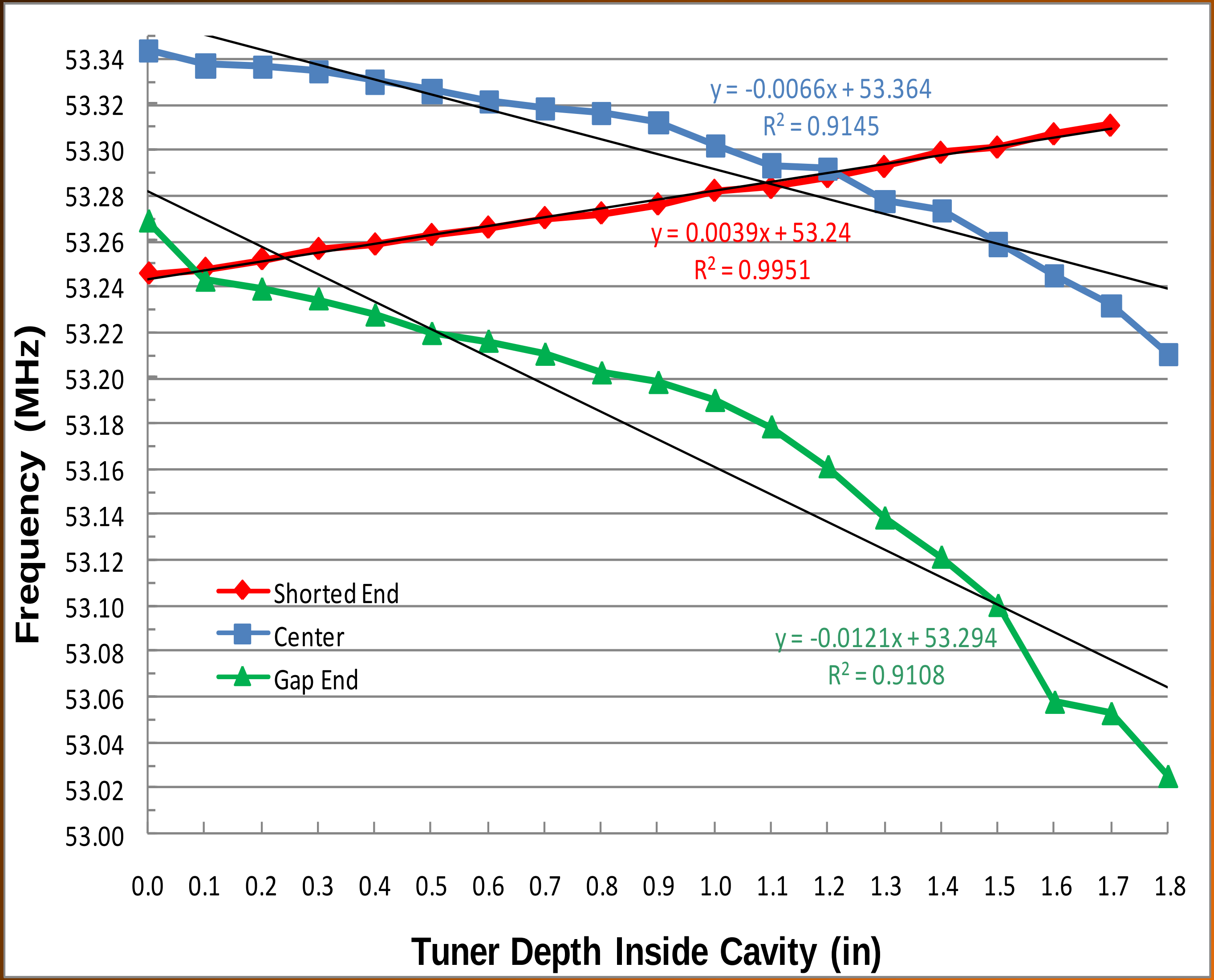


Calculated frequency:

$$\text{Tan}\,(\beta L_r) = \frac{1}{\omega R_c C_{gap}}$$

- Rc = characteristic impedance dependent upon ratio of ln (r2 /r1)
- Lr = length of inner conductor
- $\beta = 2\pi / \lambda$

Tuner Depth vs. Frequency



Tuner inserted into cavity

TEM vs. H_{m1} Ring Modes

TEM (Transverse Electromagnetic) Modes	H_{m1} Ring Modes
• Both B and E perpendicular to z. • Main mode is the first one (52.814MHz), but the other modes are unavoidable so we want to damp them.	• Magnetic field is in a different direction than TEM modes. • B field has a component in the z direction. • Differentiated from TEM by changing loop orientation. • Usually at much higher frequency but in this case the center conductor is large so they appear at lower frequencies.

TEM and H_{m1} Ring Modes

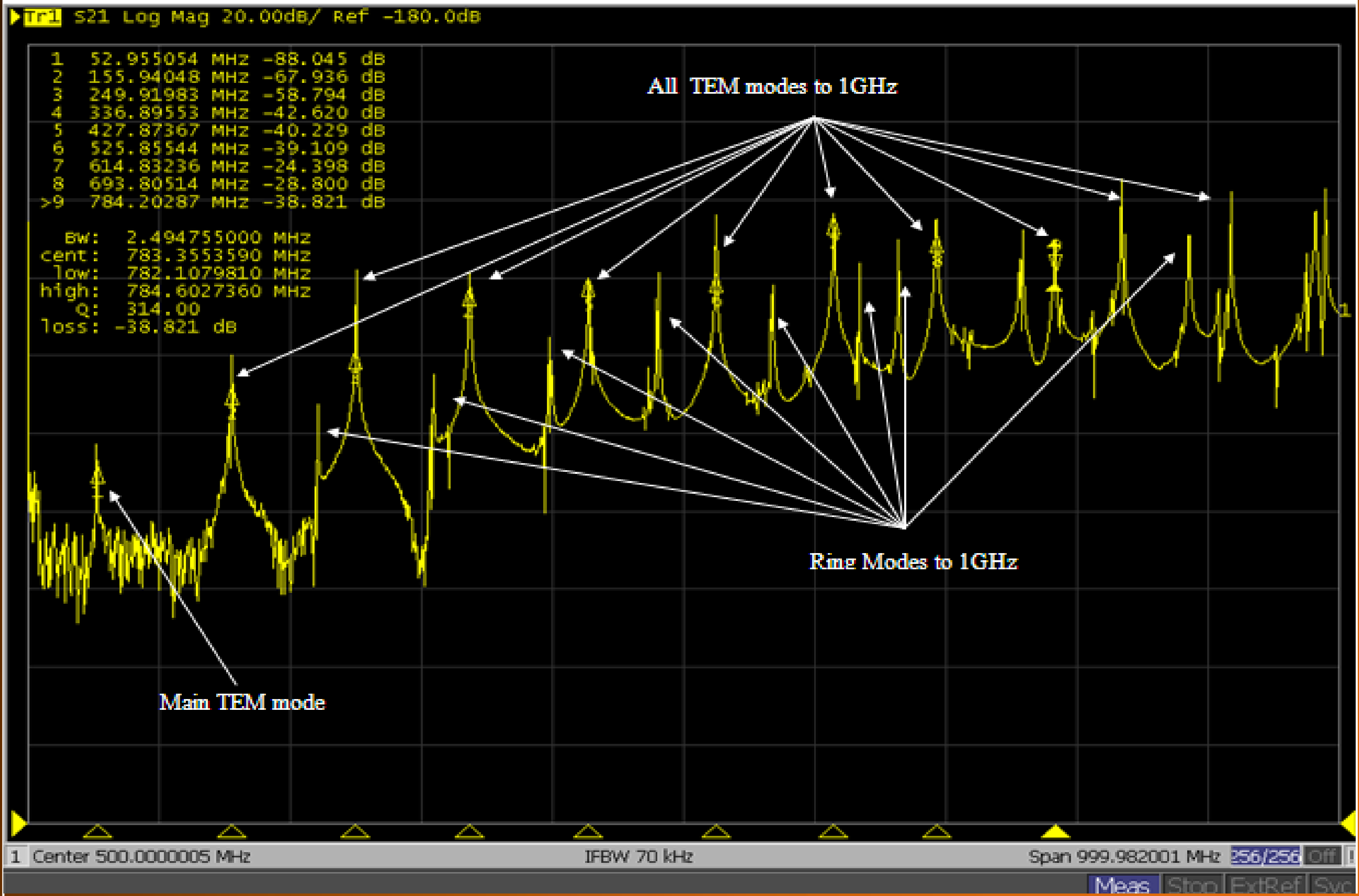


Table of Modes

Record of all modes up to 530MHz		
Measured frequency	Calculated frequency	Type of mode
52.65743	52.814	Main TEM
149.29344		
153.63287	141.0	λ/4, m=1 Ring
156.03394	158.442	3rd harmonic TEM
218.81737		
221.61862	221.0	3λ/4, m=1 Ring
250.63153	264.07	5th harmonic TEM
274.04195	261.9	λ/4, m=2 Ring
306.81203		
310.01315	312.5	3λ/4, m=2 Ring
316.27794		
321.21844	327.1	5λ/4, m=1 Ring
337.42565	369.698	7th harmonic TEM
387.04774		
391.44970	387.0	λ/4, m=3 Ring
393.85077		
397.45237	394.7	5λ/4, m=2 Ring
399.99100	422.9	3λ/4, m=3 Ring
428.41776	475.326	9th harmonic TEM
430.21889	422.9	3λ/4, m=3 Ring
430.81926		
470.84428	440.7	7λ/4, m=1 Ring
474.04628		
479.44966	486.8	5λ/4, m=3 Ring
482.85178		
487.25453	492.8	7λ/4, m=2 Ring
517.61101		
520.01251	513.3	λ/4, m=4 Ring
525.81614	580.954	11th harmonic TEM

Summary

- Built an inexpensive prototype for the NOvA project.
- Measured frequency vs. gap distance
- Measured frequency vs. tuner depth inside the cavity.
- Measured all TEM and Ring modes

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References

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